Title to come

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Speakable and Unspeakable in Quantum Mechanics. By J.S. Bell *Cambridge University Press: 1987. Pp.212. £25, $44.50.*

Niels Bohr's Philosophy of Physics. By Dugald Murdoch. *Cambridge University Press: 1987. Pp.294. £32.50, $59.50.*

A LARGE number of books have been published during the past few years on the philosophy of quantum mechanics. They divide into two main classes: popular expositions of the 'paradoxes' and attempted solutions, written generally by physicists, and technical treatises on the philosophical problems involved, written by that new species of academic expert, the philosopher of physics.

Much of the impetus for this renewed interest in the interpretive problems of quantum mechanics stems from the seminal work of John Bell in the 1960s. He challenged the assumptions that lay behind Von Neumann's famous proof of the impossibility of hidden variables in quantum theory, augmenting the incomplete description afforded by the quantum-mechanical state vector (or wave function if you prefer wave-mechanical terminology), but showing that any such 'completed' version of quantum mechanics must necessarily involve a feature of nonlocality, of apparently instantaneous action-at-a-distance. This arose from the violation, predicted by the quantum-mechanical formalism, of the famous Bell inequality, which relates certain correlation coefficients in two-particle systems prepared in so-called entangled states, typified by the singlet state of two spin-$^1/_2$ particles. This inequality was shown by Bell to be a necessary condition that must be satisfied by any theory incorporating local realism.

During the past 15 years many experiments have been carried out to test the predicted violation of the Bell inequality, culminating in the work of Aspect and his collaborators in Paris. They succeeded in showing, modulo some very plausible assumptions about the working of their apparatus, that the mysterious nonlocal action would have to be effective at spacelike separation, that is at superluminal speed of propagation. It is ironic that Bell's work supplements the Einstein–Podolsky–Rosen proof in 1935 of the incompleteness of the quantum-mechanical formalism, predicated on the absence of action-at-a-distance, by showing that a completed quantum mechanics must itself by nonlocal!

It is a great delight to see all of Bell's papers on the foundations and philosophy of quantum mechanics, many of which were published in rather inaccessible sources, collected together and reprinted by Cambridge University Press. The work of Bell falls into neither of the

two classes I mentioned at the beginning. It is serious physics, rather than popularization, but with none of the finicky logic-chopping of the philosophers. Bell always works with the simplest examples, and has an amazing talent for putting his finger right on the nerve-centre of any argument.

His view, put very simply, is that the orthodox Copenhagen interpretation, with its talk of a 'cut' between subject and object, its privileged role for classical description on the observer's side of the cut, and what Bell describes as its incomprehensible doctrine of complementarity, should be put aside in favour of the de Broglie – Bohm approach, where instead of particle *or* wave, in complementary situations, we have particle *and* wave. The wave guides the motion of the particle, just like a classical field, and everything is fully objective and well defined at all times.

Bell recognizes that an important element of the Bohrian insight remains, namely that measurement results in general are a product of both 'system' and 'apparatus', rather than revealing some pre-existing property of the 'system'. But we have to bite the bullet and accept the glaringly nonlocal features of this approach. Although the nonlocality involved is 'non-controllable', and cannot be used to send superluminal signals, there are prima facie difficulties with relativity theory. This is a very active area of research among the philosophers of physics. Bell himself poses the problem in the sharpest possible way without really attempting to solve it. He plays with the idea of an aether, picking out a preferred inertial reference frame, but one which is intrinsicially unobservable. In a paper entitled, "How to Teach Special Relativity", he emphasizes that this is a perfectly coherent way to understand relativity, following the ideas of Lorentz rather than Einstein.

Bell is generally critical of the Everett–Wheeler 'many worlds' interpretation of quantum mechanics, much espoused these days by cosmologists. He stresses the ambiguity in just when when measurements are supposed to take place and the splitting of the Universe to occur, and claims that the de Broglie – Bohm approach is a much preferable basis for the application of the whole Universe, where there is in principle nothing 'outside' to play the role of the observer.

By contrast, Murdoch's book attempts a critical assessment of the Bohr interpretation, of which Bell is so dismissive. Murdoch gives a gloss on Bohr's writings, stressing that experiments discover objective values, rather than create them, which he tries to reconcile with the thesis that quantum-mechanical systems do not have intrinsic properties that are independent of measurement. Murdoch emphasizes the influence of pragmatism on Bohr's philosophical thinking, and downgrades the Kantian elements that

other writers have discerned in it. He includes discussion of Bell's later work and concludes, on balance, that "there is no outright victor in the Bohr – Einstein contest".

Taken together, the two books given an exemplary introduction to the continuing debates about quantum mechanics. Physicists no longer have any excuse for believing that all questions of interpretation have long been answered, and, as Bell puts it, they could fully understand just how if ever they could spare 20 minutes to think about it! □

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